APPENDIX E
DESIGN AND PERFORMANCE CRITERIA

1. Pretreatment. As discussed in Appendix C, pretreatment essentially includes two categories:

- Dewatering
- Particle size adjustment

1.1 Particle Size Adjustment. A variety of size-reduction equipment is available. In general, size reduction equipment can be classified into the way in which forces are applied, as follows:

- force applied between two surfaces as in crushing and shearing;
- force applied only on one surface (impact);
- non-mechanical size reduction (thermal shock, explosive shattering).

Table E-1 shows a practical classification of crushing and grinding equipment. Selection of the appropriate equipment is based on feed size and hardness and is summarized on Table E-2. Additional information on particle adjustment can be found in Perry's Chemical Engineers' Handbook (sixth edition, Perry, 1984).

1.2 Dewatering.

1.2.1 Belt Filter Presses. Belt filter presses are the most common devices used for dewatering sludges. A typical belt filter press dewatering system consists of sludge feed pumps, polymer feed equipment, a sludge conditioning tank, belt filter press, sludge cake conveyor, and support pumps. Several parameters affect the performance of belt filter presses, including:

- Sludge characteristics (includes viscosity, specific gravity, and % weight moisture);
- Unit differential pressure;
- Machine configuration;
- Belt porosity, speed and width.

Belt filter presses are available in sizes from 0.5 to 3.5 m (1.5 to 12 ft.) in belt width. Sludge-loadings rates vary from 90 to 680 kg per meter of belt with per hour (60 to 450 lb per foot of belt per hour) depending on the sludge type and feed concentration. Hydraulic throughput based on belt widths ranges from 1.6 to 6.3 L/m s (7.7 to 30 gal/ft min). Safety

TABLE E-1
Types of Size-Reduction Equipment

A.	Jaw crushers: 1. Blake 2. Overhead eccentric 3. Dodge
B.	Gyratory crushers: 1. Primary 2. Secondary 3. Cone
C.	Heavy-duty impact mills: 1. Rotor breakers 2. Hammer mills 3. Cage impactors
D.	Roll crushers: 1. Smooth rolls (double) 2. Toothed rolls (single and double)
E.	Dry pans and chaser mills
F.	Shredders: 1. Toothed shredders 2. Cage disintegrators 3. Disk mills
G.	Rotary cutters and dicers
H.	Media mills: 1. Ball, pebble, rod, and compartment mills: a. Batch b. Continuous 2. Autogenous tumbling mills 3. Stirred ball and sand mills 4. Vibratory mills
I.	Medium peripheral-speed mills: 1. Ring-roll and bowl mills 2. Roll mills, cereal type 3. Roll mills, paint and rubber types 4. Buhrstones
J.	High-peripheral-speed mills: 1. Fine-grinding hammer mills 2. Pin mills 3. Colloid mills 4. Wood-pulp beaters
K.	Fluid-energy superfine mills: 1. Centrifugal jet 2. Opposed jet 3. Jet with anvil

Source: Perry's Chemical Engineers Handbook, 6th ed.

TABLE E-2
Guide to Selection of Crushing and Grinding Equipment

Size Reduction Operation	Hardness of Material	Size				Reduction Ratio	Types of Equipment
		Range of Feeds cm (in.)		Range of Products cm (in)			
		Max.	Min.	Max.	Min.		
Crushing							
Primary	Hard	150 (60) 50 (20)	30 (12) 10 (4)	50 (20) 13 (5)	10 (4) 2.5 (1)	3 to 1	A to D
Secondary	Hard	13 (5) 4 (1.5)	2.5 (1) 0.6 (0.25)	2.5 (1) 0.5 (0.19)	0.5 (0.2) 0.1 (0.03)	5 to 1	A to F
	Soft	50 (20)	10 (4)	5 (2)	1 (0.4)	10 to 1	C to G
Grinding Pulverizing							
Coarse	Hard	0.5 (0.19)	0.1 (0.03)	0.006 (0.02)	0.008 (0.003)	10 to 1	D to I
Fine	Hard	0.12 (0.05)	0.015 (0.006)	0.008 (0.003)	0.01 (0.0004)	15 to 1	H to K
Disintegration							
Coarse	Soft	1.3 (0.5)	0.17 (0.07)	0.057 (0.02)	0.008 (0.003)	20 to 1	F, I
Fine	Soft	0.4 (0.16)	0.05 (0.02)	0.008 (0.003)	0.001 (0.0004)	50 to 1	I to K

* 85%by weight smaller than the size given.
Source : Perry’s Cheical Engineers Handbook, 6th ed.
Values have been rounded and metric equivalents added.

considerations which should be addressed in the design include adequate ventilation and to prevent loose clothing from being caught between rollers (Metcalf and Eddy, 1991). Caution should be exercised in sizing the filter or any other equipment based on a municipal sludge application since this is an industrial waste application and may not produce a waste stream with characteristics similar to municipal sludge. Table E-3 shows the advantages and disadvantages of belt filter presses.

1.2.2 Plate and Frame Press. Plate and frame press advantages and disadvantages are listed on Table E-4 (Perry, 1984).

1.2.3 Sand Drying Beds. Sand drying beds are constructed of with fine to coarse-graded sand and gravel layers which cover an open-joint pipe drainage system. Figure E-1 is an example of a type of drying bed layer system. Table E-5 lists the design advantages and disadvantages of using drying beds. Table E-6 presents typical design criteria for drying beds.

2. Unit Design Criteria.

2.1 Feed Storage and Conveyance. Feed storage and conveyance are integral components of the thermal desorption system materials handling operation. Feed hoppers are used to collect and store contaminated materials for feeding into the thermal desorption unit. Conveyor systems are used to transport solids into and out of the desorption unit.

2.2 Feed Hopper Systems. Feed hopper systems are generally used with mobile construction equipment such as front end loaders and bulldozers to load and temporarily store contaminated materials for conveyance into the thermal desorption unit. Surge hoppers may also be installed at the desorption inlet and used with a conveyor to feed material into the desorption.

Feed hopper components are generally commercially available as preengineered units. The choice of a proper feed hopper system involves consideration of many factors that are to be considered when choosing a conveyor system. Material properties such as particle size, moisture content and temperature are important because they affect the ability of a material to flow and hence the geometry and configuration of the hopper system. Volumetric capacities of the hoppers must be sufficient to accommodate the throughput capacities of the conveyor system and thermal desorption unit.

Components may be added to feed hoppers to assist and control flow from the hopper to the conveyor system or process equipment. Slide gates are available in both manual and automated designs. Bin vibrators and vibrating bottoms may eliminate material

TABLE E-3
Advantages and Disadvantages of
Belt Filter Presses

<table>
<tr><td colspan="2"><u>BELT FILTER PRESS</u>

After chemical conditioning, the sludge is deposited onto the moving belt. The readily drainable water is removed in the gravity drainage section. Pressure is applied to the cake, squeezing it between the two belts, and the cake is subjected to flexing in opposite directions as it passes over the various rollers. This action causes increased water release and allows greater compaction of the sludge.</td></tr>
<tr><th>Advantages</th><th>Disadvantages</th></tr>
<tr><td>High pressure machines are capable of producing drier cake than any machine except a filter press</td><td>Very sensitive to incoming feed characteristics and chemical conditioning</td></tr>
<tr><td>Low power requirements</td><td>Machines hydraulically limited in throughput</td></tr>
<tr><td>Low noise and vibration</td><td>Short media (belt) life as compared with other devices using cloth media</td></tr>
<tr><td>Operation is easy to understand for an inexperienced operator because all parts are visible and results of operational changes are quickly and readily apparent</td><td>Wash water requirements for belt spraying can be significant</td></tr>
<tr><td>Process controls can be adjusted for optimum dewatering of a variety of sludge types</td><td>Frequent washdown of area around press required</td></tr>
<tr><td>Continuous operation</td><td>Can emit noticeable odors if the sludge is poorly stabilized</td></tr>
</table>

TABLE E-3 (cont)
Advantages and Disadvantages of
Belt Filter Presses

Advantages	Disadvantages
Media life can be extended when applying low belt tension	Requires greater operator attention than a centrifuge
	Condition and adjustment of scraper blades is a critical parameter that should be checked frequently
	Probably requires a chemical polymer system in order to work well, and typically requires greater polymer dosage than a centrifuge
	Requires a skilled operator
Source: Perry's Chemical Engineers Handbook, 6th ed.	

feeders, when mounted below feed hoppers, serve as effective devices for metering material to the conveyor or desorption. Selection of some common feeder types on the basis of material characterization is summarized in Table E-7. Feed hoppers may also be equipped with weigh scales or sensors to measure the weight of the material fed.

TABLE E-4
Advantages and Disadvantages of
Plate and Frame Filter Presses

PLATE AND FRAME FILTER PRESS A filter cloth is mounted over the two surfaces of each filter plate. Conditioned sludge is pumped into the filter press and passes through holes in the filter plates along the length of the filter and into the chambers. As the sludge cake forms and builds up in the chamber, the pressure gradually increases to a point at which further sludge injection would be counter-productive. The pressure is maintained for a one- to four-hour period, during which more filtrate is removed and the desired cake solids content is achieved. The filter is then mechanically opened, and the dewatered cake dropped from the chambers for removal.	
Advantages	Disadvantages
Filter presses yield higher cake solids concentration than any other class of dewatering technology	Large quantities of inorganic conditioning chemicals are commonly used for filter presses
Can dewater hard-to-dewater sludges, although very high chemical conditioning dosages or thermal conditioning may be required	Polymer alone is generally not used for conditioning due to problems with cake release and blinding of filter media
Very high solids capture	Presses are large and complex
Only mechanical device capable of producing a cake dry enough to meet landfill requirements in some locations	High capital cost especially for diaphragm filter presses
Does not require a skilled operator	Labor cost may be high if sludge is poorly conditioned and if press is not automatic
	Replacement of the media is both expensive and time consuming
	Noise levels caused by feed pumps can be very high

TABLE E-4 (cont)
Advantages and Disadvantages of
Plate and Frame Filter Presses

Advantages	Disadvantages
	Use of precoat and filtration aids result in more sludge for disposal
	Batch operation
	Large area requirements
Source: Perry's Chemical Engineers Handbook, 6th ed.	

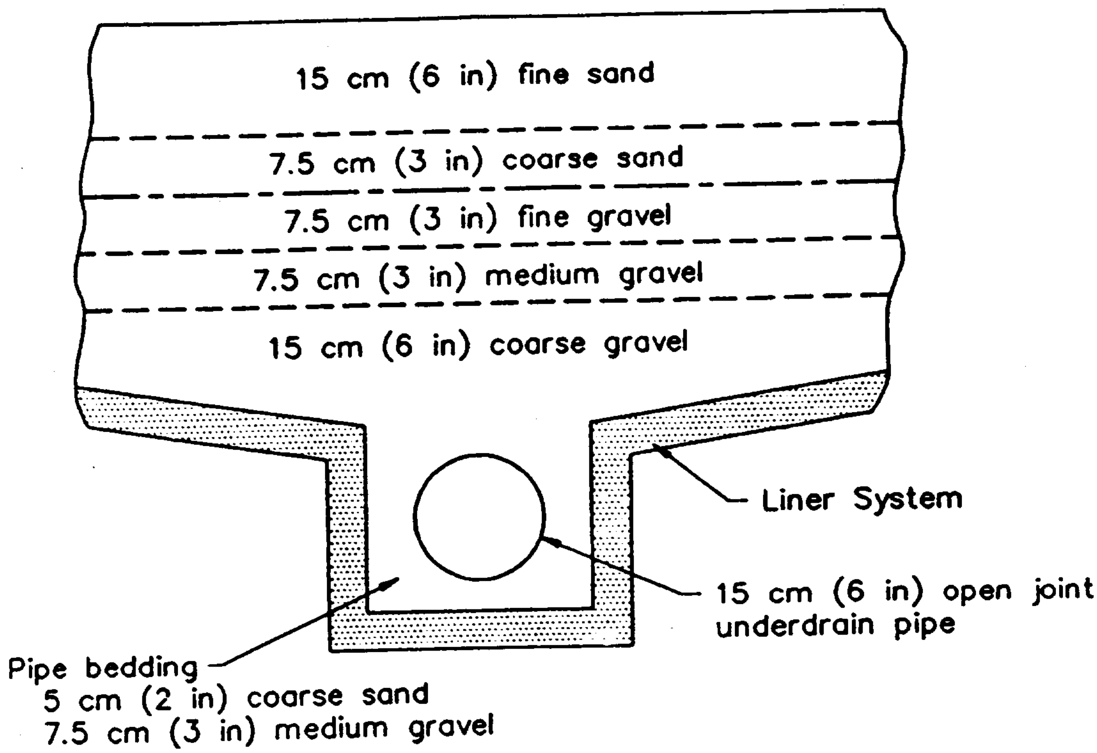


FIGURE E-1

SAND DRYING BED

TABLE E-5
Advantages and Disadvantages of Sand Drying Beds

Advantages	Disadvantages
Low capital cost (excluding land)	Weather conditions such as rainfall and freezing weather have an impact on usefulness
Low operational labor and skill requirement	
Low energy	Requires large land areas
Low maintenance material cost	High labor requirement for sludge removal
Little or no chemicals required	May be aesthetically unpleasing, depending on location
High cake solids content possible	Potential odor problem with poorly stabilized sludge
Source: Standard Handbook of Environmental Engineering by Robert A. Corbitt, McGraw Hill 1990.	

TABLE E-6
Sand Drying Bed Design Data

Parameter	Typical Value
Minimum number	Two
Shape	Rectangular
Length	6-12 m (20-200 ft)
Width	96 m (20 ft)

Sand layer
  Depth
  Effective size
  Uniformity coefficient
	
	23 cm (9 in)
	0.3-1.0 mm
	Less than 4.0

Gravel layer
  Depth
  Grading
	
	30 cm (12 in)
	3.2-25 mm (0.12-1 in)

Underdrain system
  Pipe size
  Spacing
  Slope
	
	10 cm (4 in) minimum
	Less than 6.1 m (20 ft)
	1%

Freeboard above sand	30-45 cm (12-18 in)

Area requirements
  Open
  Covered
	
	0.09-0.18 m^2/cap (1-2 ft^2/cap)
	0.06-0.13 m^2/cap (0.7-1.5 ft^2/cap)

Application depth	20-30 cm (8-12 in)
Source:Standard Handbook of Environmental Engineering, by Robert A. Corbitt, McGraw Hill, 1990.	

2.1.2 Conveyor Systems. Pre-engineered conveyor system components are commercially available in a variety of standardized designs. The common conveyor types used in thermal desorption systems are screw auger and belt type conveyors. Dragline conveyors are also used on some systems.

Selection of a conveyor suitable for the material to be handled in a specific application involves the consideration of many factors. Listed below are several important design considerations in choosing a conveyor system:

- Capacity- System throughput requirements may determine the type of conveyor utilized. Belt type conveyors because of their larger size and higher operating speeds are capable of transporting larger quantities of material then screw type feeders. Screw conveyors are available with capacities up to 283 m^3 (10,000 cubic feet) per hour. Belt conveyors can transport up to 142 m^3 (5,000 tons per hour) (Perry, 1984).

- Material Properties- The physical and chemical characteristics of the material to be handled may dictate conveyor type and/or materials of construction. Aggregate size, abrasiveness, corrosion effects, resistance to flow, density, temperature and moisture content are several key material characteristics to consider in choosing a conveyor.

- Length- The length of travel may limit the choice of certain types of conveyors. Belt and screw conveyors are capable of relatively longer travel lengths than pneumatic or vibrating conveyors.

- Lift- Belt and screw type conveyors generally can be arranged to accommodate the vertical travel required in the design of thermal desorption systems. Where only vertical travel is required, bucket elevators or specially designed screw conveyors may be considered.

- Special Processing Requirements- Screw conveyors are particularly adaptable to a variety of processing operations such as heating, cooling, mixing, dewatering, and the transport of sticky and wet materials. Screw conveyors are susceptible to jamming if oversize material is fed into the conveyor.

Selection of common conveyor types on the basis of function is provided in Table E-8. Auxiliary equipment can be added to conveyor systems to satisfy particular requirements. Both electrical and mechanical type torque limiting devices are available to prevent overloads due to jamming. Weigh scales or load cells can be installed to weigh material transported into or out of the desorption unit. Cleaning devices are available to help alleviate problems associated with sticky or non flowing materials. Safety cut off devices such as pull cords may be installed. Screw conveyors may be enclosed or the conveyor equipped with emissions control devices in applications involving transport of materials having a large amount of air borne particulates. Table E-7 provided a general guide to conveyor selection. Table E-8 provides information on feeder selection. Table E-9 provides a material classification coded list.

2.2 Desorption Design/Performance Evaluation Criteria.

To specify an appropriate desorption unit, the designer needs to specify the following design and performance criteria:

- Treatability study results;
- Material throughput capacity kg/hr (lb/hr);
- Characterization of feed stock (type, moisture criteria, organic criteria); and
- Remediation requirements.

Using the above information, desorption efficiency parameters can be developed. These critical parameters include:

- system operating temperature for the primary desorption chamber;
- turbulence induced in the primary chamber;
- solids retention time at the desorption temperature; and
- sweep gas flows through the primary chamber.

While some wide ranges for these parameters are provided in this document (see Table C-2), the specific application will require site-specific data to determine adequate values for each. In some cases, these parameters cannot be monitored directly, and less-than-full scale treatability studies or full scale demonstration tests should be used to determine values for indirect measurement that provide an indicator of adequate performance.

For instance, although monitoring the temperature of treatment effluents (e.g., treated soils) is recommended and desirable for monitoring temperature of the treatment system, this is not currently possible. Research in use of color pyrometers indicates that monitoring solids temperature may be possible in the near future. This requires the measurement of another parameter (e.g., kiln wall temperature or gas temperature). In this case, a pilot or full scale study is

TABLE E-7
Conveyors for Bulk Materials*

Function	Conveyor Type
Conveying materials horizontally	Apron, belt, continuous flow, drag flight, screw, vibrating, bucket, pivoted bucket, air
Conveying materials up or down an incline	Apron, belt, continuous flow, flight, screw, skip hoist, air
Elevating materials	Bucket elevator, continuous flow, skip hoist, air
Handling materials over a combination horizontal and vertical path	Continuous flow, gravity-discharge bucket, pivoted bucket, air
Distributing materials to or collecting materials from bins, bunkers, etc.	Belt, flight, screw, continuous flow, gravity-discharge bucket, pivoted bucket, air
Removing materials from rail cars, trucks, etc.	Car dumper, grain-car unloader, car shaker, power shovel, air

*From FMC Corporation, Material Handling Systems Division.
Source: Perry's Chemical Engineers Handbook, 6th ed.

TABLE E-8
Feeders for Bulk Materials*

Material Characteristics	Feeder Type
Fine, free-flowing materials	Bar flight, belt, oscillating or vibrating, rotary vane, screw
Non-abrasive and granular materials, materials with some lumps	Apron, bar flight, belt, oscillating or vibrating, reciprocating, rotary plate, screw
Materials difficult to handle because of being hot, abrasive, lumpy, or stringy	Apron, bar flight, belt, oscillating or vibrating, reciprocating
Heavy, lumpy, or abrasive materials similar to pit-run stone and ore	Apron, oscillating or vibrating, reciprocating

*From FMC Corporation, Material Handling Systems Division.
Source: Perry's Chemical Engineers Handbook, 6th ed.

TABLE E-9
Classification System for Bulk Solids*

Material Characteristics		**Class**
Size	Very fine - <149μm (100 mesh)	A
	Fine - 149μm to 3.18 mm (100 mesh to ⅛ in)	B
	Granular - 3.18 to 12.7 mm (⅛ to ½ in)	C
	Lumpy-containing lumps >12.7 mm (½ in)	D
	Irregular - being fibrous, stringy, or the like	H
Flowability	Very free-flowing - angle of repose up to 30°	1
	Free-flowing - angle of repose 30 to 45°	2
	Sluggish - angle of repose 45° and up	3
Abrasiveness	Nonabrasive	6
	Mildly abrasive	7
	Very abrasive	8
Special characteristics	Contaminable, affecting use or salability	K
	Hygroscopic	L
	Highly corrosive	N
	Mildly corrosive	P
	Gives off dust or fumes harmful to life	R

recommended to define the adequate temperature ranges for the applicable parameter. Information regarding treatability studies is provided in Section D.5 of Appendix D.

Each of the four parameters and its effect on desorption efficiency is discussed briefly below.

2.2.1 Temperature. A key parameter in ensuring the required material desorption is achieving material temperature. Material temperatures are always associated with a material treatment time. The parameters are dependent on each other for any discussion of thermal desorption. As the concentration of organic increases, the treatment time and/or temperature required to meet the cleanup requirement increases. The optimal temperature for desorption should be determined through previous treatability testing, and operation temperatures can be measured at one of three points:

- The soil discharge temperature, generally in the range of 150-650°C (300-1200°F). Some systems may have problems in monitoring this parameter since measuring a flowing solids temperature on a continuous basis is not presently possible.

- Kiln or dryer wall temperature, generally in the range of 150-650°C (300 to 1200°F). This provides an indirect means of measuring the solids temperature on a continuous basis, however, because the measurement is indirect, the assumption must be made that the thermal transfer to the soils is adequate for volatilization. Again, the data gathered during a demonstration or smaller scale treatability test should be used for determining the optimal temperature for an indirect measurement.

- Off gas temperature, generally 150-760°C (300-1400°F). As with monitoring temperature of the desorption device itself, monitoring off gas temperature provides an indirect means of measuring the solids temperature on a continuous basis, making the same assumption on energy transfer. The data gathered during a demonstration or smaller scale treatability test should be used for determining the optimal temperature for an indirect measurement.

The thermal desorption system should be monitored for malfunction (e.g., inadequate auxiliary firing, poor heat transfer due to fouling, excess sweep air flow) and the waste feed adjusted accordingly. Should excessive temperatures be detected by the system controls processing should cease to protect equipment.

2.2.2 Turbulence. Turbulence of the media in the primary chamber impacts volatilization of the contaminants through two mechanisms:

- By increasing contact time of each particle of the media with the heated portions of the primary chamber, thereby enhancing transfer of thermal energy to the media.

- By increasing contact time of each particle of the media with the sweep gas, both increasing heat transfer from the gas to the media and driving the vapor phase/adsorbed phase equilibrium towards the vapor phase.

In rotary dryer/rotary kiln type systems, the movement resulting from rotation of the kiln is used to enhance this interphase transfer and heat transfer effectiveness. Rotational speeds should be maintained at some prescribed minimum to allow unimpeded heat and material transfers. As with the temperatures, this rotational speed should be determined in a demonstration test or in smaller scale treatability testing. It should be realized that kiln rotational speed also impacts retention time inversely (i.e., the faster the rotational speed, in general the shorter the solids residence time). Therefore, both minimum and maximum kiln speeds should be specified based on the results of the treatability tests. Treatability and pilot scale testing utilizing rotary quartz kiln tubes (described in Appendix D) assist in the determination of operating parameters for full scale operation. Rotary quartz kiln tubes typically have refractory lined kilns with variable rotational speeds and adjustable slopes. Rotational speeds vary from 1 to 12 revolutions per minute, and slopes of the kiln range from 0 to 5.5%. The rotational speed and slope of the dryer is then adjusted to obtain the required solids retention time for a known fixed length of a reaction zone (Hazen Research Inc., 1994). This data is then translated to full scale operation by process engineering principles.

Thermal screw systems rely on direct contact of the media with the auger to transfer heat, minimizing the need for heat transfer from the sweep gas. With these systems, turbulence is induced by the heated augers and serves to increase the contact of each particle with the auger (facilitating heat transfer) and increasing contact time with the sweep gas (facilitating the vapor/solids transfer). As with rotary kiln/rotary dryer systems, an inverse relationship exists between residence time and auger speed, and optimal auger speeds should be determined during treatability tests.

2.2.3 Solids Retention Time. Retention time is the effective residence time that the soil feed remains in the desorption unit and impacts the treatment time for the media. Shorter than adequate retention times will result in incomplete desorption of the contamination due to the lack of adequate time for heat transfer to the soils or mass transfer to the sweep gas to occur. Typical retention times are from 3 to 90 minutes dependent on the type of desorption, feed rate and kiln/auger/conveyor speeds.

Solids retention time is directly related to the kiln rotational speed (for rotary kiln/rotary dryer systems) and to auger speeds (for thermal screw systems). The designer or construction manager should also realize that particles of differing size will move at different speeds through the system (for instance, in general, larger particles will move more quickly through a rotating kiln than smaller particles) making absolute definition of retention time difficult. Although approximate retention times can be determined initially using dyes, retention times may be difficult to monitor directly during operations and the operators may need to rely on indirect controls, such as auger speed or kiln rotational rate.

The required solids retention time and corresponding temperature should be determined by treatability testing or demonstration studies.

2.2.4 Sweep Gas. Sweep gas (a low oxygen carrier gas or air) acts as a carrier to remove volatilized materials from the desorption chamber, driving the solid/vapor equilibrium towards the vapor phase. Sweep gas carrying the soil contaminants is then carried to the gas conditioning system and then either exhausted or recycled to the desorption chamber. As a secondary function, in some systems the sweep gas serves as a heat carrier and transfer agent to heat the soils, as, for instance, in a fluidized bed type system.

Although each system should be capable of adequately handling a wide range of gas flow rates, the rate is critical in affecting the performance of the system. A low flow rate will not allow adequate sweeping of the system, and the solid/vapor equilibrium may favor the solid phase. A flow rate too high may not provide adequate heat transfer time between the gas and solid and higher levels of particulate may be entrained into the gas, overloading the control system. Again, an adequate sweep gas flow should be determined in treatability studies.

Determination of the sweep gas flow rate is dependant on the type of thermal desorption unit (direct fired or indirect fired), type of sweep gas (oxidative or inert) used, the purge gas oxygen concentration, contaminants present in soil, and moisture content of the soil. Specifically, the sweep rate can be determined using the volume or capacity if the thermal desorption, the diameter of the purge gas inlet, and knowing the percent turnover rate within the chamber. Actual sweep rate can be measured using a calibrated rotameter.

Sweep gas flow rates are highly dependent on the specific system in use and a range for acceptable sweep gas flows should be determined during the treatability studies or demonstration testing.

2.3 Particulate Control. As discussed in Appendix C, particulate control devices primarily consist of cyclones, bag houses, and Venturi Scrubbers. The type of particulate control and unit efficiency is dependant on the amount and size of particles entering the system. Methods to estimate what type of particulate control can be determined by knowing both the concentration of influent particulates and the associated size distribution. Note that with the proposed EPA standards of 0.015 gr/cu ft, baghouses may be the only particulate control device capable of meeting this requirement in the future. Table E-10 provides associated efficiencies and particle sizes for cyclones, baghouses and Venturi Scrubbers.

2.3.1 Cyclones. The two main classifications of cyclones are based on efficiency:

- High-efficiency cyclones; and
- High-through put cyclones.

High-through put cyclones are typically used to remove particle sizes greater than 50 µm, and generally have large diameters. High-efficiency cyclones have small diameters (less than 0.3 m (1 foot)).

The factors typically considered when designing cyclones include the following:

- Dust size distribution, particle density, shape, physical chemical properties such as agglomeration, hygroscopic tendencies, stickiness, etc.;
- Contaminated gas stream temperature, pressure, humidity, condensable components, density, etc. ;
- Process variables such as dust concentration, gas flow rate, allowable pressure drop, size to be separated; and
- Structural limitations, temperature and pressure rating, materials of construction, and space limitations.

TABLE E-10
Collection Efficiencies for Particulate Control Equipment

Equipment Type	Percentage Efficiency at		
	50 µm	5 µm	1 µm
Medium-efficiency cyclone	94	27	8
Low-resistance cellular cyclones	98	42	13
High-efficiency cyclone	96	73	27
Venturi scrubber, medium energy	100	>99	97
Venturi scrubber, high energy	100	>99	98
Shaker-type fabric filter (Bag house)	>99	>99	99
Reverse-jet fabric filter (Bag house)	100	>99	99
Source: Lapple, C., Interim Report: Stack Contamination - 200 Areas, HDC-611, August 6, 1948.			

It is important to understand the factors that affect the performance of cyclones which are the following:

- Secondary effects: This includes the mass transfer related issues which decrease the efficiency of the cyclone. An example of this type of effect is the bouncing back of particles into the inner vortex of the cyclone;

- Proportional Dimensions: High efficiency cyclones have certain dimensional proportions which are based on the results of extensive investigations. Table E-11 is a summary of the performance trends based on cyclone changes. Figure E-2 provides a sketch of the dimensions of a single cyclone separator.

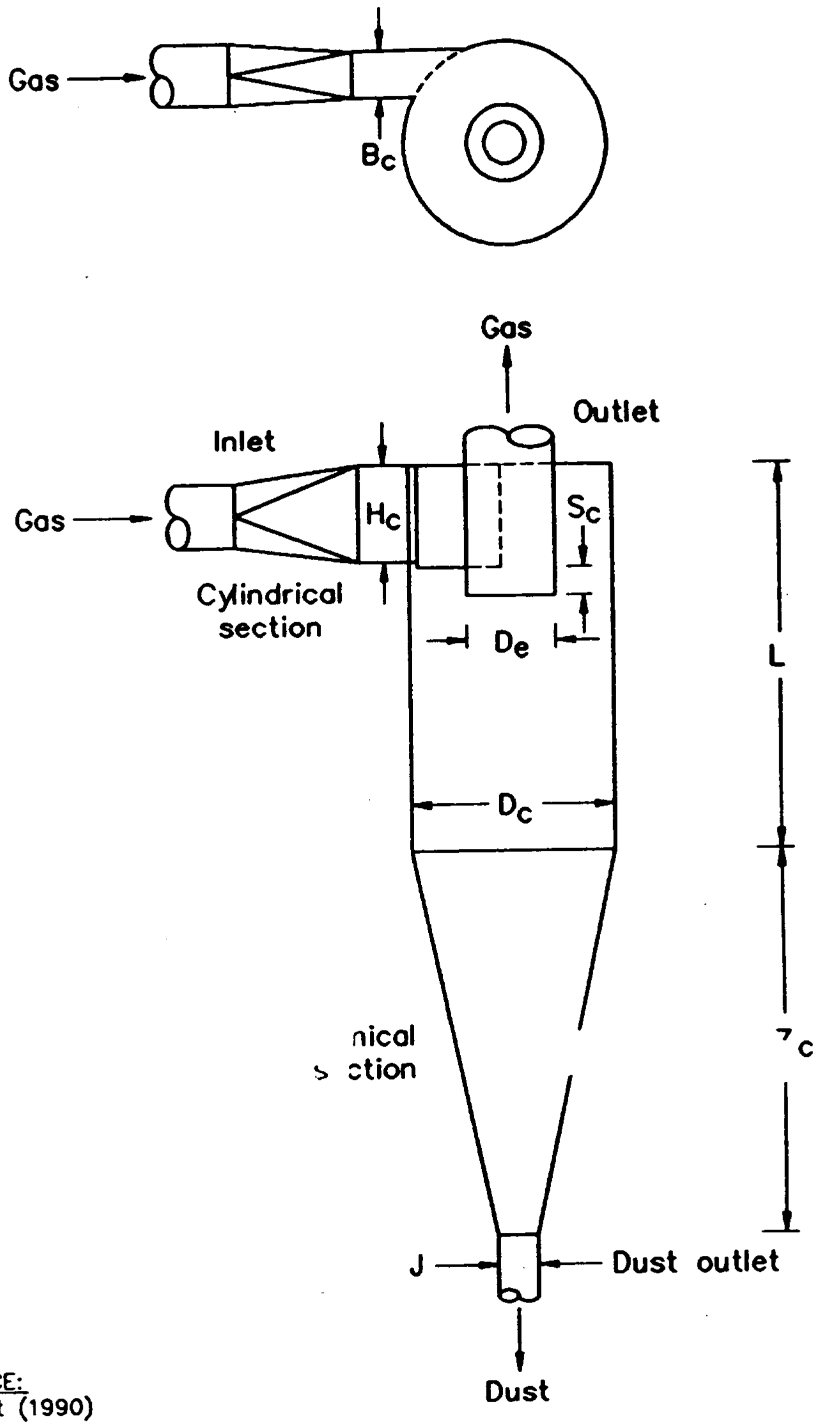
- Physical properties: The physical properties which affect the performance of a cyclone include the specific gravity of the carrier gas, particle size, and viscosity of the carrier gas.

- Process variables: The effect of changes in gas velocity, temperature, dust loading is indicated in Table E-12. It should be noticed that an increase in efficiency also tends to increase the pressure drop. Excessive pressure drop affects the collection efficiency.

TABLE E-11
Performance Trends Based on Cyclone Changes

Proportional Change	Performance Trend		Cost Trend
	Pressure Loss	Effic-iency	
Increase cyclone size	Down	Down	Up
Lengthen cylinder	Slightly lower	Up	Up
Increase inlet area - maintain volume	Down	Down	-
Increase inlet area - maintain velocity	Up	Down	Down
Lengthen cone	Slightly lower	Up	Up
Increase size of cone opening	Slightly lower	Up or down	-
Decrease size of cone opening	Slightly higher	Up or down	-
Lengthen clean gas outlet pipe internally	Up	Up and/or down	Up
Increase clean gas outlet pipe diameter	Down	Down	Up

Source: Control Technologies for Hazardous Air Pollutants, June 1991. EPA-625-691-014.



SOURCE:
Corbitt (1990)

FIGURE E-2

DIMENSIONS SINGLE CYCLONE SEPARATOR

2.3.2 Baghouses. As discussed in Appendix C baghouses or fabric filters are the most efficient means of separating particles from a gas stream. Important process variables considered in baghouse design include the following:

- Fabric type;
- Cleaning methods;
- Air-to-cloth ratio; and
- Equipment configuration (i.e., forced draft or induced draft).

The fabric type, cleaning method, and air-to-cloth ratio all should be selected concurrently. Equipment configuration is of secondary importance unless the space for the equipment is limited. The operating parameter usually monitored is the pressure drop across the system. Typically baghouses are operated within certain pressure drop range, which is determined based on site experience.

The data required for the design consists of the following:

- Flow rate actual m^3/s (acfm);
- Moisture content (%);
- Temperature °C (°F);
- Particle mean diameter (μm);
- SO_3 content (ppm);
- Particulate content $\mu g/m^3$ (grains/scf); and
- Organic content (%).

Table E-13 is a summary of the characteristics of several fibers used in fabric filtration. Table E-14 is a comparison of fabric filter cleaning methods. Table E-15 is a summary of recommended ranges of air-to-cloth rations by typical bag filters for a variety of dusts and fumes.

TABLE E-12
Effect of Physical Properties Process Variables on Efficiency

	Pressure Loss	Efficiency	Cost Trend
Gas Change			
Increase velocity	Up	Up	Initial cost down, operating cost up
Increase density	Up	Neg	Slightly higher
Increase viscosity	Neg	Down	-
Increase temperature (maintain velocity)	Down	Down	-
Dust Change			
Increase specific gravity	-	Up	-
Increase particle size	-	Up	-
Increase loadings	-	Up	-

Source: Control Technologies for Hazardous Air Pollutants, June 1991. EPA-625-691-014.

TABLE E-13
Characteristics of Several Fibers Used in Fabric Filtration

Fiber Type[a]	Max. Operating Temp.	Resistance[b]				
		Abrasion	Mineral Acids	Organic Acids	Alkalis	Solvent
Cotton[c]	82°C (180°F)	VG	P	G	P	E
Wool[d]	93°C (200°F)	F/G	VG	VG	P/G	G
Modacrylic[d] (Dynel™)	71°C (160°F)	F/G	E	E	E	E
Polypropylene[d]	93°C (200°F)	E	E	E	E	G
Nylon Polyamide[d] (Nylon 6 & 66)	93°C (200°F)	E[f]	F	F	E	E
Acrylic[d]	127°C (260°F)	G	VG	G	F/G	E
Polyester[d]						
(Dacron[h])	135°C (275°F)	VG	G	G	G	E
(Creslan™)	121°C (250°F)	VG	G	G	G	E
Nylon Aromatic[d] (Nomex™)	191°C (375°F)	E	F	G	E	E
Fluorocarbon[d] (Teflon™, TFE)	232°C (450°F)	F/G	E[f]	E[f]	E[f]	E[f]

TABLE E-13 (cont)
Characteristics of Several Fibers Used in Fabric Filtration

Fiber Type[a]	Max. Operating Temp.	Resistance[b]				
		Abrasion	Mineral Acids	Organic Acids	Alkalis	Solvent
Fiberglass[c]	260°C (500°F)	F/G[g]	G	G	G	E
Ceramics[i] (Nextel 312™)	480+°C (900+°F)	-	-	-	-	-

[a]Fabric limited.
[b]P = poor resistance, F = fair resistance, G = good resistance, VG = very good resistance, and E = excellent resistance.
[c]Woven fabrics only.
[d]Woven or felted fabrics.
[e]Considered to surpass all other fibers in abrasion resistance.
[f]The most chemically resistant of all these fibers.
[g]After treatment with a lubricant coating.
[h]Dacron™ dissolves partially in concentrated H_2SO_4.
[i]The ceramic fiber market is a very recent development. As a result, little information on long term resistance, and acid and alkali performance has been documented.

Source: Control Technologies for Hazardous Air Pollutants, June 1991. EPA-625-691-014.

TABLE E-14
Comparison of Fabric Filter Bag Cleaning Methods

Parameter	Cleaning Method			
	Mechanical Shake	Reverse Air flow	Pulse-jet Individual Bags	Pulse-jet Compartmented Bags
Cleaning on- or off-line	Off-line	Off-line	On-line	Off-line
Cleaning time	High	High	Low	Low
Cleaning uniformity	Average	Good	Average	Good
Bag attrition	Average	Low	Average	Low
Equipment ruggedness	Average	Good	Good	Good
Fabric type[a]	Woven	Woven	Felt/Woven[a]	Felt/Woven[a]
Filter velocity	Average	Average	High	High
Power cost	Low	Low to Medium	High to Medium	Medium
Dust loading	Average	Average	Very high	High
Maximum temperature[b]	High	High	Medium	Medium
Collection efficiency	Good	Good	Good[c]	Good[c]

[a]With suitable backing, woven fabrics can perform similarly to felted.
[b]Fabric limited.
[c]For a properly operated system with moderate to low pressures, the collection efficiency may rival other methods.

Source: Control Technologies for Hazardous Air Pollutants, June 1991. EPA-625-691-014.

TABLE E-15
Air-to-Cloth Ratios[a]

Dust	Shaker/Woven Reverse-Air/Woven[b]	Pulse Jet/Felt[b]
Alumina	0.76 (2.5)	2.4 (8)
Asbestos	0.91 (3.0)	3.1 (10)
Bauxite	0.76 (2.5)	2.4 (8)
Carbon black	0.46 (1.5)	1.5 (5)
Coal	0.76 (2.5)	2.4 (8)
Cocoa, chocolate	0.76 (2.5)	3.7 (12)
Clay	0.76 (2.5)	2.7 (9)
Cement	0.61 (2.0)	2.4 (8)
Cosmetics	0.46 (1.5)	3.1 (10)
Enamel frit	0.76 (2.5)	2.7 (9)
Feeds, grain	1.07 (3.5)	4.3 (14)
Feldspar	0.67 (2.2)	2.7 (9)
Fertilizer	0.91 (3.0)	2.4 (8)
Flour	0.91 (3.0)	3.7 (12)
Fly ash	0.76 (2.5)	1.5 (5)
Graphite	0.61 (2.0)	1.5 (5)
Gypsum	0.61 (2.0)	3.1 (10)
Iron ore	0.91 (3.0)	3.4 (11)
Iron oxide	0.76 (2.5)	2.1 (7)
Iron sulfate	0.61 (2.0)	1.8 (6)
Lead oxide	0.61 (2.0)	1.8 (6)
Leather dust	1.07 (3.5)	3.7 (12)
Lime	0.76 (2.5)	3.1 (10)
Limestone	0.82 (2.7)	2.4 (8)
Mica	0.82 (2.7)	2.7 (9)

TABLE E-15 (cont)
Air-to-Cloth Ratios[a]

Dust	Shaker/Woven Reverse-Air/Woven[b]	Pulse Jet/Felt[b]
Paint pigments	0.76 (2.5)	2.1 (7)
Paper	1.07 (3.5)	3.1 (10)
Plastics	0.76 (2.5)	2.1 (7)
Quartz	0.85 (2.8)	2.7 (9)
Rock dust	0.91 (3.0)	2.7 (9)
Sand	0.76 (2.5)	3.1 (10)
Sawdust (wood)	1.07 (3.5)	3.7 (12)
Silica	0.76 (2.5)	2.1 (7)
Slate	1.07 (3.5)	3.7 (12)
Soap detergents	0.61 (2.0)	1.5 (5)
Spices	0.82 (2.7)	3.1 (10)
Starch	0.91 (3.0)	2.4 (8)
Sugar	0.61 (2.0)	2.1 (7)
Talc	0.76 (2.5)	3.1 (10)
Tobacco	1.07 (3.5)	4.0 (13)
Zinc oxide	0.61 (2.0)	1.5 (5)

[a]Generally safe design values - application requires consideration of particle size and grain loading.
[b]A/C ratio units are $(m^3/min)/m^2$ of cloth area $[(ft^2/min)/ft^2$ of cloth area$]$

Source: Control Technologies for Hazardous Air Pollutants, June 1991. EPA-625-691-014.

2.3.3 Venturi Scrubbers. Venturi scrubbers are designed to collect particles between 0.5 to 5.0 μm in diameter. The data necessary to perform design consists of the following:

- Flow rate actual m^3/sec (acfm);
- Moisture content (%);
- Temperature °C (°F);
- Particle mean diameter (μm);
- Required collection efficiency (%);
- Particulate content μg/m^3 (grains/scf); and
- Organic content (%).

The temperature range for venturi scrubber should be within 5 to 38 °C (50 to 100 °F). If the temperature does not fall within the stated range then pretreatment of the stream may be necessary (i.e., stream cooling).

The two most import considerations for evaluating a venturi scrubber are the pressure drop across the scrubber and the material of construction. Typical pressure drops for venturi scrubbers for a variety of applications are listed in Table E-16. Materials of construction for various industries are listed in Table E-17 and serve as a general guide as to the types of material used in the industry.

2.4 Air Pollution Control Devices Design and Performance. Air pollution control devices are designed to remove organics/THC/VOC/POHC from the thermal desorption unit discharge gas flow. These unit operations include:

- Thermal afterburners
- Catalytic afterburners
- Adsorption
- Baghouses
- Wet scrubbers

Performance is based on criteria developed to meet stack emission (regulatory requirements) criteria and/or process recycle requirements.

This section details the design and performance of these unit operations.

2.4.1 Afterburners. To ensure satisfying stack emission requirements, thermal or catalytic afterburners may be required. The process principle involves the combustion and oxidation of hydrocarbons/VOC's. The unit design (process and equipment) is based on the following four key criteria:

TABLE E-16
Pressure Drops for Typical

Venturi Scrubber Applications

Application	Pressure Drop	
	kPa	in H_2O
Boilers		
Pulverized coal	3.7 - 10	15 - 40
Stoker coal	2.5 - 3	10 - 12
Bark	1.5 - 2.5	6 - 10
Combination	2.5 - 3.7	10 - 15
Recovery	7.5 - 10	30 - 40
Incinerators		
Sewage sludge	4.5 - 5	18 - 20
Liquid waste	12.4 - 13.7	50 - 55
Solid waste		
Municipal	2.5 - 5	10 - 20
Pathological	2.5 - 5	10 - 20
Hospital	2.5 - 5	10 - 20
Kilns		
Lime	3.7 - 6.2	15 - 25
Soda ash	5 - 10	20-40
Potassium chloride	7.5	30
Coal Processing		
Dryers	6.2	25
Crushers	1.5 - 5	6 - 20
Dryers		
General spray	5 - 15	20 - 60
Food spray	5 - 7.5	20 - 30
Fluid bed	5 - 7.5	20 - 30

Source: Control Technologies for Hazardous Air Pollutants, June 1991.
EPA**-625-691-014.**

TABLE E-17
Construction Materials for Typical Venturi Scrubber Applications

Application	Construction Material
Boilers	
Pulverized coal	316L stainless steel
Stoker coal	316L stainless steel
Bark	Carbon steel
Combination	316L stainless steel
Recovery	Carbon steel or 316L stainless steel
Incinerators	
Sewage sludge	316L stainless steel
Liquid waste	High nickel alloy
Solid waste	
Municipal	316L stainless steel
Pathological	316L stainless steel
Hospital	High nickel alloy
Kilns	
Lime	Carbon steel or stainless steel
Soda ash	Carbon steel or stainless steel
Potassium chloride	Carbon steel or stainless steel
Coal Processing	
Dryers	304 or 316L stainless steel
Crushers	Carbon steel

Source: Control Technologies for Hazardous Air Pollutants, June 1991. EPA-625-691-014.

- Temperature: for a thermal unit a range of 760-982°C (1400-1800°F) is required to support the destruction of the hydrocarbon molecular structures; for a catalytic unit a range of 320-650°C (600-1200°F) is adequate; however, temperatures of 1204°C (2200°F) have been used for difficult-to-oxidize organics.

- Residence time: unit sizing is based on providing residence times ranging from 0.5 to 2.0 seconds - this allows for the time required for complete combustion.

- Catalyst and contact turbulence: thorough gas mixing to insure gas phase interaction and temperature uniformity is required - this is achieved by proper selection of chamber velocities 3.05 - 6.1 m/sec (10 to 20 ft/sec), burner arrangement in the chamber to allow for flame/gas flow interaction (which may reflect a direct or tangential entry) and the use of pinch points (narrowing/obstruction of the gas flow path).

- Oxygen concentration: to ensure proper reaction/conversion, minimum oxygen concentrations of 3-5% should be maintained in the flue gas with the sources being the desorption flue, burner supply and supplementary air fan as needed. Maximum values of 7-9% O_2 should not be exceeded due to the generation of excess flue gas flow.

Design of the afterburner chamber should include, consistent with the above criteria, the following considerations:

- Chamber volume based on the maximum gas flow and maximum required residence time, with the width of the chamber computed from the gas velocity and the chamber length.

- Afterburners may be provided in horizontal or vertical configurations. Vertical is the preferred arrangement should solids drop out be a concern. Provisions for removal of solids should be provided (i.e., bottom hopper, manway access).

- Afterburner chambers are typically refractory-lined units with the shell being of a carbon steel. The selection of a refractory type should widen (a) the operating temperature constructed including the temperature profile at the burner zone which may dictate refractor type due to elevated flame temperatures, (b) the presence of acid gases or corrosive materials, and (c) material thicknesses including insulation, if required, to maintain a shell temperature of less than 260°C (500°F).

- To conserve energy, heat exchange between the influent and effluent streams may be incorporated including (a) recirculating a portion of the exit flow and mixing this flow with the inlet stream and (b) using a non-contact heat exchanger, internal to the afterburner unit, or as a separate stand alone device.

A burner arrangement should be selected to support the above design criteria (e.g., temperature requirements). The burner design may include the following considerations:

- Use of an appropriate fuel supply (fuel oil, natural gas and/or propane).
- Use of single or multiple units for back up.
- Burner thermal duty with consideration given to the flue gas inlet flow rate, flue gas composition (complimenting combustion of the organics present) and the maximum design combustion mix temperature.
- Flame/gas flow interaction (e.g., direct, tangential) and gas phase turbulence to promote the combustion reaction.
- Use of a low NO_x design.

Within the limits of the overall air pollution control system train, thermal afterburners need to achieve the following performance criteria:

- Organics/THC/VOC/POHC: destruction and removal efficiency (DRE) of 95-99.9+% or 10-100 ppmv concentration.
- CO: 2-100 ppmv (rolling average).
- Nitrogen oxides (NO_x): less than 100 ppmv.

The performance of afterburners should also meet the specific operational requirements - most notably combustion zone temperature, gas discharge oxygen levels, and negative pressure (via the APL system ID fan) to meet regulatory requirements.

2.4.2 Catalytic Afterburner. To meet stack emission regulations, catalytic afterburners may be required. Catalytic afterburners use a noble metal catalyst to promote the rate of reaction and decrease the activation energy needed for oxidation, allowing operation at lower temperatures and thereby yielding lower fuel usage.

Key matters to note regarding the application of catalyst afterburners are:

- Catalyst materials normally used are platinum, palladium, and rhodium. Others include copper chromite and the oxides of copper, chromium, manganese, nickel and cobalt.

- Common commercially available catalyst configurations include mat (similar in appearance to an air filter), porcelain assemblies and plates with connected rods and honeycomb (ceramic or refractory) supported catalysts, where the catalyst material is deposited in layers on an inert substrate.

The gas stream should be free of particulate matter to protect the catalyst from fouling. In addition, catalysts are sensitive to many substances, including platinum poisons (heavy metals), suppressants (halogens), and fouling agents (iron oxides).

The design of catalytic afterburners is based on the following four key criteria:

- Temperature: to support ignition and combustion an operating temperature range of 320-650°C (600-1200°F) is required - achieved through the combustion reactions and auxiliary fuel firing.

- Residence time: unit/catalyst bed sizing is based on residence times ranging from 0.08 to 1.0 seconds to allow time for complete reaction.

- Turbulence: the shell and catalyst should be configured to provide intimate mixing of the gas phase flow and contact with the catalyst structure.

- Oxygen concentration: sufficient oxygen must be present to insure oxidation of the contaminants; minimum levels of 3-5% O_2 should be maintained in the gas flow with the sources being the desorption flue burner supply and supplementary air fan as needed, and maximum oxygen concentrations of 7-9% should not be exceeded due to the generation of excess flue gas flow.

The precise value of each of these parameters is dependent on the catalyst employed plus the flue stream properties.

Design of the afterburner chamber should consider:

- Catalyst volume based on the maximum gas flow and maximum required residence time.

- Chamber construction for operating temperatures: below 540°C (1000°F) heat treated steels have been used successfully, at temperatures near 540°C (1000°F) stainless steels may be use, and above 540°C (1000°F) refractory linings are used.

- To conserve energy recuperative heat recovery schemes may be provided integral to the afterburner unit or as a separate stand along device including:(a) recirculating part of the exit flow and mixing with the inlet stream and (b) using a non-contact heat exchanger.

- Noble metal catalysts are susceptible to the following:poisons (arsenic compounds, halogens, phosphates and heavy metals); fouling agents (silicones, iron oxides and alumina dusts); and suppressants (halogens and sulfur compounds)(Brunner, 1988).

A burner arrangement should be selected to support the above design criteria (e.g., temperature requirements). The burner design should consider

- Use of an appropriate fuel supply (fuel oil, natural gas and/or propane).
- Use of single or multiple units for back up.
- Burner thermal duty with consideration given to the flue gas inlet flow rate, flue gas composition (complimenting combustion of the organics present) and the maximum design combustion mix temperature.
- Flame/gas flow interaction and gas phase turbulence and promote the combustion reaction.
- Use of a low NO_x design.

Within the limits of the overall air pollution control system train, catalytic afterburners typically need to achieve the following performance criteria:

- Organics (THC/VOC/POHC): destruction and removal efficiency (DRE) of 90-99%.
- CO: 2-100 ppmv (rolling average).
- Nitrogen oxides (NO_x): less than 100 ppmv.

The performance of catalytic afterburners should also meet the specific operational requirements; most notably of which are reaction zone temperature, gas discharge oxygen concentrations and negative pressure (via the APC system ID fan) to meet regulatory requirements.

2.4.3. Adsorption. Vapor phase activated carbon or resin adsorption may be employed within the APC train to further remove organic constituents in the cooled flue gas stream and satisfy emission requirements.

Characterization of the organic contaminants is a key consideration in the selection of an appropriate adsorbent. Organic contaminants are characterized as follows:

- Compound name
- Formula and/or molecular weight
- Specific gravity
- Inlet concentration
- Boiling point
- Vapor pressure curve
- Adsorption isotherms
- Refractive index

Impurities and safety must be considered (e.g., dust may clog the adsorbent bed, ketones may oxidize or polymerize, both of which will liberate heat with a potential for ignition of the adsorbent).

In addition to the above, to select an appropriately sized adsorption unit the following criteria must be known:

- Air flow rate m^3/s, (cfm)
- Air pressure atm, (psig)
- Air relative humidity, %
- Temperature, °C (°F)
- Capture efficiency, %
- Characterization of constituents of concern

Design considerations for the selection of a carbon absorber are:

- Relative humidity of off-gas. Off-gas normally has a relative humidity of 100%. Uncontrolled humidity reduces the efficiency and effectiveness of carbon adsorption.
- Materials of construction for the vessels and internals are lined (high solids epoxy, polyethylene) carbon steel, stainless steel, fiberglass, polypropylene, etc. and that the fabrications are readily available to the site.
- Arrangement of air distributors to maximize flow patterns to support interphase contact and reduce the gas side pressure drop.
- Clean and fouled pressure drops to support the system draft profile.

- Upflow, downflow or crossflow configuration requirements.
- Pre-filters to avoid unwanted fugitive particulate build up in the adsorbent bed.
- Accessories such as blowers or fans, premixing, skid mounting, control panels, post-filters, flame arrestors, sample ports, lifting lugs, pressure relief valves, rupture disks, condensate traps, separators, dehumidifiers.
- Code requirements (e.g., ASME pressure testing) and/or leakage testing.
- Provisions for carbon replacement.
- Provisions for carbon regeneration
- Regeneration system requirements (e.g., boilers, heated pressure air/steam flow, stripped material collection and separation, treatment and routing).

While dependent on the overall air pollution control system train, the adsorption system needs to achieve the performance criteria for organics (THC/VOC/POHC) of 50 to 99% removal primarily as a function of the outlet temperature, chemical types, inlet concentration, adsorbent bed depth and bed velocity.

Additional performance criteria may also be required to conform with regulatory requirements (e.g., inlet temperature).

2.5 Treated Material Handling. Thermal desorption systems typically employ screw or belt type conveyor systems to transport treated material residuals from the desorption outlet to a truck or storage area. Conveyor arrangements may include a single conveyor or multiple conveyors involving changes in both horizontal and vertical direction.

The design criteria used in the selection of an appropriate solids effluent conveyor system is generally similar to that for the desorption inlet conveyor system. Material temperatures, however, warrant closer consideration in selecting conveyors for solid effluents. Soil discharge temperatures of certain types of thermal desorbers may approach 650°C (1200°F) and may affect the materials of construction and/or type of conveyor chosen. In rotary dryer and thermal screw type desorption systems, water may be sprayed unto the hot soil in a screw conveyor for cooling and dust control.

As with the desorption inlet conveyor systems, auxiliary devices may be added to satisfy particular requirements.

2.6 Oversized Material Handling. Depending on the hazardous/nonhazardous nature of the oversized material, there are several management options available. If hazardous, stone clumps and aggregate can be reprocessed in a pug mill or crusher and then treated in the desorption unit. Boards, plastic, and miscellaneous debris can be decontaminated and sent to a solid waste landfill for disposal. The liquid generated and residue can be treated in the facility wastewater treatment plant.

If nonhazardous, all oversized material can be sent off-site for disposal in a solid waste landfill.

3. Process Controls. This section will present (1) the instrumentation and control elements used in a thermal desorption system design, (2) different degrees of automation and (3) a list of minimal process control components that may be used in a thermal desorption system.

3.1 Description of Design Elements. A full thermal desorption system design will include, at a minimum, the following process control elements:

3.1.1 Process Flow Diagram. Flow and material balances showing the general arrangement of the equipment, the flow rate of each process stream, the operating temperature and pressure for each unit process, and the composition of materials on each process stream.

3.1.2 P&I Diagrams. Piping and instrumentation diagrams show the interrelationship between process components, piping and process control devices. ISA and ANSI standards (ANSI/ISA-S5.1) govern the preparation of P&I diagrams. These diagrams show all major process components organized according to process flow. The instrumentation symbols are shown in "bubbles."

3.1.3 Electrical Wiring Diagram. This diagram shows the wiring of all physical electrical devices, such as transformers, motors and lights. If appropriate, the diagram is organized in ladder logic form.

3.1.4 Description of Components. The specifications must include a description of instrumentation and control components including installation and mounting requirements.

3.1.5 Sequence of Control. The sequence of control must be included in both the design submittal and the operation and maintenance manual. Control information concerning system start-up, system shutdown and response to malfunctions must be included.

3.1.6 Control Panel Layout. A control panel layout must be designed. This drawing will show, to scale, all electrical components and the associated wiring. This control item is normally submitted as a shop drawing.

3.1.7 Logic Diagram. If the process control logic is not apparent from the P&I Diagram a logic diagram should be included. The diagram shows the logical (and, or, nor, if-then) relationships between control components but does not show interconnecting process flow. For example, the diagram may show that if switch #2 is placed in the on position and there are no alarm conditions, then the blower will turn on and activate a green indicator light.

3.1.8 Legend and Standard Symbols. The set of documents must have a legend to explain the symbols used. Despite the existence of the legend, standard symbols must be used wherever applicable.

3.2 Degrees of Automation. The degree of automation is generally dependent on the complexity of the treatment system, the remoteness of the site, and monitoring operations, and control requirements. Typically, there is a trade off between the initial capital cost of the instrumentation and control equipment, and the labor cost savings in system operation.

Generally, there are three forms of process control: local control, centralized control, and remote control. In a local control system, all control elements (i.e., indicators, switches, relays, motor starters) are located adjacent to the associated equipment. In a centralized control system, the control elements are mounted in a single location. These systems may include a hard-wired control panel, a programmable logic controller (PLC) or a computer. Remote control can be accomplished several ways including by means of modems or radio telemetry.

To select the appropriate control scheme, the advantages and disadvantages of each control scheme must be considered. A localized control system is less complex, less expensive and easier to construct. For example, if a level switch in a tank is controlling an adjacent discharge pump, it would obviously be simpler to wire from the tank directly to the adjacent pump than to wire from the tank to the centralized control panel and then from the panel back to the pump. As the control system becomes more complex, it quickly becomes advantageous to locate the control components in a central location. Centralized control systems are also easier to operate. Instrument interlocks can be used for both safety and equipment protection considerations. Centralized data acquisition and control may include the use of computers or PLCs.

TABLE E-18
Instrumentation Summary

Equipment	Parameter	Instrument
Desorber	Temperature	Thermocouple or Infrared Sensor
	Pressure	Pressure Transducer
	Rotational/Linear Speed	AC Variable Speed Drive or Sensing Head
	N_2 Concentration	N_2 Analyzer
	Fuel Feed Rate	Volumetric Flowmeter
	Gas Residence Time/Sweep Gas Velocity	Averaging type pitot tube
Condenser	Temperature	Thermocouple/Level Switch
Particulate Removal (Cyclone)	Differential Pressure	Differential Pressure Transducer
Air Pollution Control		
Afterburner (if used)	Temperature	Thermocouple or infrared sensor
	Fuel Feed Rate	Volumetric Flowmeter
	O_2 Concentration	Zirconium Oxide
	Burner Control	Burner Management System
Quench Chamber	Temperature	Thermocouple
	Liquor Flow	Volumetric Flowmeter
Scrubber	Differential Pressure	Differential Pressure Transducer
	Temperature	Thermocouple
	pH (Neutralization Tank)	pH Cell

TABLE E-18
Instrumentation Summary

Equipment	Parameter	Instrument
Scrubber (Cont.)	Density (Neutralization Tank)	Density Meter
Baghouse	Temperature	Thermocouple
	Differential Pressure	Diff Press Transducer
Carbon Adsorber	Temperature	Thermocouple
	Differential Presure	Differential Presure Transducer
	HC Concentration	HC Analyzer
Material Handling Desorber	Waste Feed Rate	Variable speed drive
		Load cell, weight sensor
		Programmable Logic Controller
	Residual Discharge Feed Rate	Load cell, weight sensor
		Programmable Logic Controller
Stack	CO Concentration	Infrared Analyzer
	SO_2 Concentration	Ultra Violet Photometric Detector
	NO_x Concentration	Chemiluminescent Analyzer
	Total HC	CEMS
	Opacity	Opacity Meter
	Temperature	Thermocouple
Special Equipment	Regenerate Flow Rate	Volumetric Flowmeter
Ion Exchange Unit (Wastewater)	Conductivity	Conductivity Cell
	Temperature	Thermocouple or RTD
	Pressure	Pressure Transducer

The greater the number of control inputs, the more worthwhile it is to use computer or PLC control. For thermal desorption systems, the inputs may include signals from speed indicators, pressure switches or thermocouples. The threshold for using PLCs or computers is generally between five and ten inputs, depending on the type of input and operator background. Often plant operators will be more familiar with traditional hard-wired control logic than with control logic contained in software. However, process logic contained in software is easier to change than hard-wiring. Therefore, if extensive future modifications to the proposed system may be anticipated, avoid hard-wiring the process logic.

Modems and radio telemetry can be used to control these systems remotely. Radio telemetry is typically used over shorter distances when radio transmission is possible. Modems are used with computerized control systems. Systems can also be equipped with auto dialers to alert the operator of a malfunction by telephone or pager. Considerations such as site location, capital cost, standardization, operator background and system complexity govern the selection of these devices.

3.3 Process Control Components. A listing of typical process control components typically installed in a thermal desorption system can be found in Table E-18.

3.4 Feed Storage and Conveyance.

3.4.1 Feed Hopper Systems. Bin level controls may be used on larger hoppers to monitor the contents of the hoppers. Rotary airlocks and feeders may be equipped with speed and torque overload controls similar to those used on conveyor systems. Vibrating bottoms may be controlled manually or automatically via preset timers. Signals from weight sensors together with bin level and feeder speed and torque overload sensors may be processed through programmable logic controllers to provide for the complete automation of weighing, feeding and conveying functions.

3.4.2 Conveyor Systems. Process controls are installed on conveyor systems to monitor and control one or more of the following parameters:

3.4.2.1 Conveyor Speed. Conveyor systems can be equipped with both fixed speed and variable speed drives. Fixed speed drives are used when the speed of the conveyor does not require adjustment during operation. Fixed speed drives may include the use of motor speed reducers alone or in combination with chain and sprocket drives or V-belt drives. Fixed drives are used when major changes to processing feed rates and high feed rate accuracies are not required. Variable speed drives will yield a much greater accuracy and variability in processing feed rate and speed adjustment than fixed speed drives. Variable speed drives include variable frequency drives for use with AC induction motors and silicone controlled rectifiers for use with DC motors. DC drives are preferred when speed adjustments are required over a wide range at extremely accurate settings.

3.4.2.2 Material Weight. Conveyor systems can be equipped with sensing elements (e.g., load cells, strain gauges or weigh belts or platforms) to weigh materials during processing. Material weighing may be done on a batch or continuous basis. Batch weighing is effective when material densities are constant and uniform flow can be maintained. Batch weighing devices such as additive weight and loss of weight scales can achieve accuracies of ± 0.1 percent under such conditions and when they are augmented with proper flow controls. Continuous weighing devices such as weigh platforms sense both material flow rate and changes in flow rate. Continuous weighing devices are suitable for continuous processes and can achieve weighing accuracies of ± 1 percent.

3.4.2.3 Material Feed Rate. With the use of automated process control devices such as programmable logic controllers, signal outputs from weighing devices can be combined with those of the conveyor speed controls to yield highly accurate measurement and control of material feed and discharge rates.

3.4.2.4 Torque Overload. Torque overload devices are installed on conveyor systems to prevent damage to conveyor components in the event the conveyor jams. Torque overload devices may be mechanical or electrical in design. Mechanical devices such as shear pins and slip clutches provide an immediate positive disconnection of the conveyor and drive. The conveyor system must remain inoperative, however, until the shear pins are replaced. Electrical devices include motor current sensing devices; these devices may not shut the conveyor down immediately upon increased torque and thus may not be suitable protection in some applications.

3.5 Desorption Design/Performance Evaluation Criteria. Four basic parameters can be used to monitor the performance of a thermal desorption on a continuous (or intermittent) basis. These parameters are:

- system operating temperature for the primary desorption chamber;
- turbulence induced in the primary chamber;
- retention time (can be estimated); and
- sweep gas flows through the primary chamber.

Temperature of the media in the primary chamber is ideally monitored by direct measurement of the treated materials, however, this is not possible on a continuous basis. Two alternate temperature measurements are suggested:

- Kiln or dryer wall temperature; or
- Exhaust (i.e., back end of the desorption chamber) gas temperature.

Again, each of these provides an indirect means of measuring the solids temperature on a continuous basis, but because the measurement is indirect, the assumption must be made that the thermal transfer to the soils is adequate for volatilization.

No direct manner of measuring turbulence or solids retention time can be made, however, indirect turbulence monitoring can be performed by monitoring kiln rotational speed or auger speeds (for a thermal screw system). Again, minimum and maximum speeds should be established during the treatability or demonstration testing.

Sweep gas flow rates may be measured via feed flows, recirculating gas flows and/or thermal discharge flue rate - using line velocities to determine mass and volumetric rates.

3.6 Particulate Control. The primary process control parameter monitored for cyclones, bag houses, and Venturi Scrubbers is the pressure drop across the unit. Differential pressure may be sensed by a diaphragm or similar type pressure transducer.

Temperature is also monitored in the baghouse to ensure that damage to the fabric filter does not occur.

Temperature is monitored using thermocouple sensors.

3.7 Air Pollution Control Devices Controls. Air pollution control devices provided to remove organics/THC/VOC/POHC from the thermal absorber unit discharge gas flow include the following:

- Thermal afterburners
- Catalytic afterburners
- Adsorbers
- Baghouses
- Wet scrubbers

Monitoring and controls are provided for each operation and among the overall processes to support performance and safety.

This section details the monitoring and controls of these unit operations.

3.7.1 Thermal Afterburners. Process controls required to monitor and control the thermal afterburner unit performance include the following:

- Temperature: to support combustion, a minimum temperature (e.g., 650°C (1200°F) must be maintained. Also, to protect equipment and conserve fuel, a maximum temperature is established (e.g., 980°C (1800°F)). For monitoring, generally redundant back-up thermocouples are provided in the combustion zone. This temperature range is achieved by modulating the burner firing rate for heat input and the supplemental air fan (dampers may be employed) for cooling control

- Oxygen: To support reaction chemistry a minimum oxygen level is desired (e.g., 3%) and to limit the mass flow generated a maximum oxygen concentration (e.g., 9%) is set. Monitoring is provided via the use of oxygen sensors in the combustion zone. Control within this concentration range is achieved by modulating a supplemental air fan arrangement (dampers may be employed).

- Draft: A proper system draft/pressure profile shall be maintained by monitoring different point(s) along the process train: where one of these locations may be the afterburner. Minimum pressure should be maintained to ensure a negative draft profile in the entire system to avoid fugitive releases via a modulating damper arrangement on the fan. The required draft is dependent on the system design with the afterburner itself generally requiring a 0.01 to 0.5 kpa (0.05 to 2 inch water column) pressure drop.

- Carbon Monoxide.

- Burner fuel use - an in-line flow measuring device is typically included to provide flow rate and totalization data for overall operational evaluation and inventory control purposes.

To insure the protection of the equipment, a waste feed cut-off to the thermal desorption unit should be initiated upon the following occurrences:

- low or high temperature
- low oxygen concentration
- low draft and
- related power failure.

3.7.2 Catalytic Afterburners. Specific process controls for the catalytic unit are required to monitor and control the operation of the unit. These include the following:

- Temperature: To support initiation of reactions, a minimum temperature (e.g., 316°C (600°F)) must be maintained. In addition, to protect the catalyst and equipment (recognizing their respective design temperatures) and conserve fuel, a maximum temperature is set (e.g., 649°C (1200°F)). For monitoring, generally redundant back-up thermocouples are provided in the catalyst bed zone. This temperature range is achieved by modulating the burner firing rate for heat input and the supplemental air fan (dampers may be employed) for cooling control

- Oxygen: To support reaction chemistry a minimum oxygen level is desired (e.g., 3%) and to limit the mass flow generated a maximum oxygen concentration (e.g., 9%) is set. Monitoring is provided via the use of oxygen sensors in the catalyst bed zone. Control within this concentration range is achieved by modulating a supplemental air fan arrangement (dampers may be employed).

- Draft: A proper system draft/pressure profile shall be maintained by monitoring different point(s) along the process train where one of these locations may be the afterburner. Minimum pressure should be maintained to ensure a negative draft profile in the entire system to avoid fugitive releases via a modulating damper arrangement on the fan. The required draft is dependent on the system design with the afterburner itself generally requiring a 0.0 to 0.5 kPa (0.00 to 2 inch WC) pressure drop.

Monitoring of the catalytic afterburner operation shall include - in addition to the above control parameters -the following key items:

- Burner fuel use - an in-line flow measuring device is typically included to provide flow rate and totalization data for overall operational evaluation and inventory control purposes.

- CO monitor - an on-line analyzer shall be located at the discharge of the catalyst to indicate loss of catalyst effectiveness (e.g., due to poisoning, fouling) chamber.

To protect the equipment, a waste feed cut-off to the thermal desorption unit can be initiated upon the following occurrences:

- low or high temperature
- low oxygen concentration
- low draft
- high CO discharge
- high pressure drop in the baghouse and
- related power failure.

3.7.3 Adsorption. Adsorption systems are typically provided with process controls to monitor and control performance. Components may include the following:

- Saturation Indicators: analyzers may be provided at the absorber(s) discharge to indicate the presence of organics and adsorbent bed saturation, hence the need for replacement/regeneration. Should parallel or series unit arrangements be provided, analyzers at the different unit discharge points can dictate gas routing or flow to allow for absorber servicing.

- Pressure Monitoring: pressure indicators may be provided on the inlet and outlet flow lines of the absorber or alternatively differential pressure indication may be specified.

- Temperature Monitoring: temperature indicators (with thermowells) may be placed in the absorber beds - the number required dependent on the unit size and design; the purpose is to indicate the high temperatures (due to adsorption exotherms, contaminant oxidation, polymerization reactions, etc.) which could lead to bed fires. Set points should be established which initiate on high (emergency) condition an alarm activation of the fire suppression water system and purging of the absorber bed.

Series and parallel absorber unit arrangements can be provided to allow for placing individual units out-of-service for regeneration and to maintain overall operation on-line availability.

3.8 Treated Material Handling. Process controls for the treated material handling conveyor systems are generally similar to those of the desorption inlet conveyor systems with the addition of flow controls for water sprays, if used. Control may be manual via a hand valve in applications where material throughput and temperature vary infrequently during processing; automated flow controls may be needed in applications where these parameters require frequent adjustment.

4. Site Requirements.

4.1 Equipment Plot Requirements. Space requirements for the thermal desorption processing equipment are generally less than 45 m by 45 m (150 feet by 150 feet) exclusive of materials handling equipment (EPA, 1994). Site areas required for conveyance and heavy construction equipment will vary depending upon the capacity of the treatment system and the complexity of the remediation operation. The space available for materials handling and the location of treatment and support facilities can be determined from the pre-construction survey.

4.2 Material Stockpiles. An adequate stockpile of contaminated material is necessary to allow for continuous operation. A treated material stockpile is required to allow for sampling and analyses prior to final placement.

4.3 Construction Zones. Refer to ER 385-1-92 Safety and Occupational Health Document Requirements for Hazardous, Toxic and Radioactive Wastes (HTRW) which covers construction zones to the extent required for investigation, design and construction.

4.4 Easements. Easements may be required from the local municipalities having jurisdiction over the site area. Permits and site inspections may be required for the construction of buildings and the connection to electrical, gas, water and sanitary sewer facilities.

4.5 Utility Requirements. Utility requirements (electric power, water, fuel, air, steam, etc.) will be site and contractor specific and dependent upon the capacity, type and complexity of the treatment system used. Applicable codes (military or state and local) governing the installation of utilities will be incorporated.